# LOW/HIGH TEMPERATURE SUBSTRATE HOLDER TO REDUCE EDGE ROLLOFF AND BACKSIDE DAMAGE

## Related Application

**[0001]** This application incorporates by reference the entire disclosure of U.S. Patent Application Serial No. 10/331,444, entitled "SUBSTRATE HOLDER WITH DEEP ANNULAR GROOVE TO PREVENT EDGE HEAT LOSS," filed December 22, 2002.

## Background of the Invention

### Field of the Invention

**[0002]** The present invention relates generally to substrate holders in semiconductor manufacturing apparatuses and, in particular, to substrate holders configured to maintain uniform heating.

### Description of the Related Art

**[0003]** High-temperature ovens, or reactors, are used to process substrates for a variety of reasons. In the electronics industry, substrates such as semiconductor wafers are processed to form integrated circuits. A substrate, typically a circular silicon wafer, is placed on a substrate holder. If the substrate holder helps to attract radiant heat, it is called a susceptor. The substrate and substrate holder are enclosed in a reaction chamber, typically made of quartz, and heated to high temperatures by a plurality of radiant heat lamps placed around the quartz chamber. In an exemplary high temperature process, a reactant gas is passed over the heated substrate, causing the chemical vapor deposition (CVD) of a thin layer

of the reactant material onto a surface of the substrate. Through subsequent processes, these layers are made into integrated circuits.

[0004] It is generally desirable to maintain a uniform temperature throughout the substrate holder during substrate processing. Typically, the substrate temperature closely tracks that of the substrate holder. Non-uniformities in the temperature of the substrate holder result in non-uniformities in the substrate temperature. These temperature gradients can leave the substrate susceptible to crystallographic slip in the single-crystal substrate and epitaxial layers, and possible device failure. Thus, temperature uniformity is desirable to minimize these problems. Another reason why it is desirable to maintain a uniform temperature throughout the substrate holder is to prevent differences in the quality of the film deposited on the substrate. Generally, for other semiconductor fabrication processes (e.g., etching, annealing, deposition), temperature gradients in the substrate result in different rates of reaction, and thus non-uniformities, throughout the substrate.

[0005] Using state of the art apparatuses and methods, temperature uniformity has been achieved throughout most of the combination of the substrate and the substrate holder. However, it has recently been found that with larger substrates (e.g., 300 mm wafers), it is difficult to keep the radially outer region of the substrate/holder combination (the "combination") as hot as the inner region. This is because the radially outer region experiences greater convective and conductive heat loss and, in many existing apparatuses, receives less direct radiation.

[0006] The radially outer region of the substrate/holder combination experiences greater convective heat loss than the remainder of the combination because the outer region has a generally vertical side edge and, hence, a larger surface area at which heat loss occurs for a given volume or mass. The outer region of the combination can also lose conductive heat due to contact with other equipment. These disparities in heat loss between the radially outer region and the remainder of the combination result in a lower temperature in the outer region. This temperature disparity produces a different deposition rate and deposited film thickness near the outer edge of the substrate. Accordingly, a processed substrate is typically characterized by an "exclusion zone" near the substrate edge, within which active devices are not manufactured and within which the deposited film has non-uniform qualities.

[0007] Some prior art attempts to minimize or remove the exclusion zone have focused upon directing a greater amount of radiant energy to the radially outer, as opposed to inner, region of the substrate holder during processing, in order to lessen the disparity in heat loss between such regions. Other attempts have focused upon providing a hot annular structure (e.g., a temperature compensation ring) near the periphery of the substrate holder, to reduce the heat loss from the outer region. While these efforts have been helpful, some disparity in heat loss between the inner and outer regions remains. Using state of the art processing methods and apparatuses, the annular thickness of exclusion zones is generally about 10-20 mm, while chip manufacturers strive to enforce exclusion zones to as small as 1 mm to 3 mm to maximize yield. A need exists to further shrink the exclusion zone.

## Summary of the Invention

[0008] In one aspect, an apparatus for processing a substrate is provided. The apparatus comprises a substrate holder having a support element configured to support a substrate of a particular size in a support plane defined by the support element. The support element comprises an annular veined ring supporting an outer edge of the substrate when the substrate is supported on the support element. In a preferred embodiment of the invention, the support element comprises an annular ring having a plurality of veins, where the veins are angled or spiraled to stop gas flow to the backside of the substrate. In this embodiment, there are preferably at least 300 veins in the annular veined ring. In a preferred embodiment, the substrate holder also has a raised annular ring positioned radially inward of the support element.

[0009] In another aspect, an apparatus for processing a substrate is provided, comprising a reaction chamber, a plurality of radiant heating elements configured to heat the reaction chamber, and a substrate holder in the reaction chamber. The substrate holder has a thickness defined as a distance between generally parallel top and bottom surfaces of the substrate holder. The substrate holder has one or more support elements configured to support a substrate of a particular size within a support plane defined by the one or more

support elements. The support elements comprise a plurality of veins configured in an annular ring to support an outer edge of the substrate.

**[0010]** In another aspect, an apparatus for processing a substrate is provided. The apparatus comprises a susceptor having a support surface sized to support a substrate of a particular size in a support plane, wherein the support plane is formed by top surfaces of a plurality of veins.

**[0011]** In yet another aspect, a method of manufacturing an apparatus for processing a substrate is provided. A substrate holder is formed of graphite. The substrate holder has one or more support elements configured to support a substrate of a particular size in a support plane defined by the one or more support element. The one or more support elements comprise a plurality of veins configured on an annular ring to support an outer edge of the substrate. A first annular groove is formed in the substrate holder and is configured to surround an outer edge of the substrate when the substrate is supported on the one or more support elements. A second annular groove is also formed in the substrate holder and is positioned radially inward of the one or more support elements. Finally, the substrate holder is coated with SiC.

**[0012]** For purposes of summarizing the invention and the advantages achieved over the prior art, certain objects and advantages of the invention have been described herein above. Of course, it is to be understood that not necessarily all such objects or advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

**[0013]** All of these embodiments are intended to be within the scope of the invention herein disclosed. These and other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description of the preferred embodiments having reference to the attached figures, the invention not being limited to any particular preferred embodiment(s) disclosed.

## Brief Description of the Drawings

[0014] Figure 1A is a top plan view of a conventional substrate holder;

[0015] Figure 1B is a partial cross-sectional view of the substrate holder of Figure 1A, taken along line 1B-1B of Figure 1A;

[0016] Figure 1C is a partial cross-sectional view of the substrate holder of Figures 1A and 1B, shown with a substrate held thereon;

[0017] Figure 1D is a graph illustrating the thickness of a deposited chemical layer across the surface of a semiconductor substrate, using a conventional substrate holder;

[0018] Figure 2 is a schematic, cross-sectional view of an exemplary reaction chamber with a substrate supported on a substrate holder therein;

[0019] Figure 3A is a top plan view of a substrate holder according to an embodiment of the present invention, in which the holder has a veined substrate support surface defined by a plurality of veins configured in an annular ring;

[0020] Figure 3B is a partial cross-sectional view of the substrate holder of Figure 3A, taken along line 3B-3B in Figure 3A;

[0021] Figure 3C is an enlarged view of a portion of Figure 3A indicated by arrows 3C-3C in Figure 3A;

[0022] Figure 3D is an enlarged view of a portion of Figure 3C indicated by arrows 3D-3D in Figure 3C;

[0023] Figure 3E is a cross-sectional view of an of the substrate holder 200 along the line 3E-3E in Figure 3D;

[0024] Figure 4 is a bottom plan view of the substrate holder of Figures 3A-3E;

[0025] Figure 5A is a top plan view of a substrate holder according to another embodiment of the present invention, in which the holder has a raised feature near the edge of the holder; and

[0026] Figure 5B is a schematic cross-sectional view, taken along line 6B-6B in Figure 5A, of a portion of a substrate holder according to the embodiment of the present invention shown in Figure 5A.

## Detailed Description of the Preferred Embodiment

**[0027]** While the claimed invention is described in the context of CVD, it will be understood that the invention described herein is applicable to other types of thermal processing, including etching annealing, oxidation, nitridation, reduction and ALD. As noted above in the Background of the Invention section, processed substrates are typically characterized by an exclusion zone at the outer radial portion of each substrate, within which the deposited film has non-uniform qualities. This non-uniformity of the substrate is due in part to non-uniformity in temperature of the substrate holder upon which the substrate is supported. The outer radial portion of a typical substrate holder loses heat convectively at a greater rate than the remainder of the substrate holder. This disparity in the rate of heat loss is due to the outer radial portion of the substrate holder having a larger surface area over which heat loss can occur. The outer radial edge of the substrate holder also loses some heat conductively due to contact with other equipment. In addition, in most existing semiconductor processing apparatuses, the vertical side edge of the substrate holder receives less direct radiant heat than the remainder of the substrate holder. As a result, the outer radial portion of the substrate holder has a lower temperature than the remainder of the holder, which in turn results in the aforementioned non-uniformities in the outer radial portion of the processed substrate supported by the substrate holder.

**[0028]** Figures 1A-1D illustrate this concept. Figures 1A-1C show a conventional substrate holder 1 for supporting a substrate 2, such as a semiconductor wafer, during processing. Figures 1A and 1B show the substrate holder 1 alone without the substrate 2. Figure 1A is a top plan view, and Figure 1B is cross-sectional view of one side of the substrate holder 1. Figure 1C is a view similar to that of Figure 1B, showing a substrate 2 supported on the substrate holder 1. The substrate holder 1 includes an inner pocket area 3 defined by an annular wall 4. The pocket area 3 is sized and configured to receive and support the substrate 2 (e.g., circular and slightly larger than a 300 mm wafer). The wall 4 separates the pocket area 3 from a raised annular shoulder 5. The shoulder 5 is located

radially outward of the pocket 3. The substrate holder 1 has an annular side surface 6 and a bottom surface 7.

**[0029]** During substrate processing, the substrate holder 1 absorbs heat, typically from radiant heat lamps surrounding the reaction chamber. U.S. Patent No. 6,121,061, which is incorporated by reference, describes a typical configuration of radiant heat sources in an exemplary CVD reactor. The substrate holder 1 also loses heat to the surrounding environment (e.g., to the chamber walls, which are not perfectly reflective). Some of this lost heat is re-radiated to the substrate holder 1, while the rest is lost by convection and conduction. With reference to Figure 1C, the substrate holder 1 loses heat from its upper surfaces 3 and 5, side surface 6, and bottom surface 7, and the substrate 2 loses heat from its upper surface 9. The arrows $H_T$ schematically illustrate the heat loss at the upper surfaces 3, 5, and 9. Similarly, the arrows $H_S$ and $H_B$ schematically illustrate the heat loss at the side surface 6 and the bottom surface 7, respectively. Throughout most of the holder/substrate combination, the heat loss $H_T$ and $H_B$ is typically compensated with uniform heat input across the combination surface of the holder/substrate. Thus, there is a relatively uniform temperature throughout the upper surface of the holder/substrate combination (there may be some vertical temperature gradients). However, there is additional heat loss $H_S$ at the outer radial edge of the holder/substrate combination, which receives less direct radiation from the radiant heat lamps and is thus not compensated by heat input. This additional heat loss results in a lower temperature at the outer radial edge of the holder 1 and substrate 2. Consequently, the substrate holder design shown in Figures 1A-1C normally results in some degree of processing non-uniformities within an "exclusion zone" bordering the substrate edge 8. Furthermore, the additional heat loss at the edges induces temperature gradients from the center of the substrate to the edges, as heat flows radially outward.

**[0030]** Figure 1D is a graph that illustrates the thickness of a chemical vapor deposited (CVD) layer across the surface of a 200-mm semiconductor substrate, using a conventional substrate holder such as the substrate holder 1 shown in Figures 1A-C. This test was conducted on a rotating substrate (i.e., the substrate was rotated about its vertical center axis). In Figure 1D, the horizontal axis represents the horizontal location on the surface of the substrate. The value 0 mm represents the leading edge of the substrate, and

200 mm represents the trailing edge. The vertical axis represents the localized layer thickness divided by the mean layer thickness throughout the surface of the substrate. The localized layer thickness of the deposited layer is shown only from 3-197 mm on the horizontal axis. This is because it is very difficult to measure the thickness of the chemical deposition layer within the three millimeters bordering the substrate edge, which is often rounded. As shown in Figure 1D, the use of a conventional substrate holder leads to a significant reduction of the thickness of the deposited layer at the edges of the substrate. This "edge roll-off" effect is caused by the lower temperature at the outer radial edge of the substrate/holder combination.

[0031] Previous studies have indicated that the substrate holder is generally cooler than the substrate during processes such as CVD. During low temperature processes, the normal contact point, which is usually the edge perimeter of the substrate, between the substrate holder and the substrate has the best conductive thermal contact and is the point where most heat loss from the substrate to the substrate holder occurs. There are other mechanisms that also contribute to the temperature losses between the edge of the substrate and the environment. The edge roll-off compensation features of the preferred embodiments permit additional heat input to the substrate from the front, side, and rear radiant heat lamps of the apparatus, and thermally isolate this additional heat input as close to the edge of the substrate as possible.

[0032] The preferred embodiments help to achieve a smaller exclusion zone. A substrate holder design that significantly reduces heat losses at the outer radial edge of the holder/substrate combination and, thus, helps to shrink the achievable size of the exclusion zone is provided. Before presenting the details of a preferred embodiment of the substrate holder of the invention, it will be instructive to illustrate an exemplary reactor within which the inventive substrate holder can be used for processing substrates, such as semiconductor wafers.

[0033] Figure 2 illustrates an exemplary chemical vapor deposition (CVD) reactor 10, including a quartz reaction chamber 12. Radiant heating elements 14 are supported outside the transparent chamber 12, to provide heat energy to the chamber 12 without appreciable absorption by the chamber walls. Although the preferred embodiments are

described in the context of a "cold wall" CVD reactor, it will be understood that the substrate support systems described herein can be used in other types of reactors and semiconductor processing equipment. Skilled artisans will appreciate that the claimed invention is not limited to use within the particular reactor 10 disclosed herein. In particular, one of skill in the art can find application for the substrate support systems described herein for other semiconductor processing equipment, wherein a substrate is supported while being uniformly heated or cooled, particularly where the support is subject to edge losses near the substrate edge. Moreover, while illustrated in the context of standard silicon wafers, the supports described herein can be used to support other kinds of substrates, such as glass, which are subjected to treatments such as CVD, physical vapor deposition (PVD), etching, annealing, dopant diffusion, photolithography, etc. The supports are of particular utility for supporting substrates during treatment processes at elevated temperatures.

**[0034]** The radiant heating elements 14 typically include two banks of elongated tube-type heating lamps arranged in orthogonal or crossed directions above and below a susceptor holding a semiconductor substrate. Each of the upper and lower surfaces of the substrate faces one of the two banks of heating lamps 14. A controller within the thermal reactor adjusts the relative power to each lamp 14 to maintain a desired temperature during wafer processing. There are also spot lamps that are used for compensating for the heat sink effect of lower support structures.

**[0035]** The illustrated substrate comprises a semiconductor wafer 16 with a generally circular edge 17, shown in Figure 2 supported within the reaction chamber 12 upon a substrate support structure 20. The illustrated support structure 20 includes a substrate holder 100, upon which the wafer 16 rests, and a spider 22 that supports the holder 100. The substrate holder 100, shown in greater detail in Figures 3A-3E (described below), is only one of a number of preferred embodiments of the present invention. The spider 22 is preferably made of a transparent and non-metallic (to reduce contamination) material. The spider 22 is mounted to a shaft 24, which extends downwardly through a tube 26 depending from the lower wall of the chamber 12. The spider 22 has at least three substrate holder supporters or arms 25, which extend radially outward and upward from the shaft 24. The arms 25 are preferably separated by equal angles about a vertical center axis of the shaft 24, which is

preferably aligned with a vertical center axis of the substrate holder 100 and wafer 16. For example, if there are three arms 25, they are preferably separated from one another by 120°. The arms 25 are configured to support the bottom surface of the substrate holder 100. In a preferred embodiment, the substrate holder 100 comprises a susceptor capable of absorbing radiant energy from the heating elements 14 and re-radiating such energy. It is preferable that the upper surface of the holder 100 is solid and made of one piece. Preferably, the shaft 24, spider 22, and holder 100 are configured to be rotated in unison about a vertical center axis during substrate processing.

**[0036]** A central temperature sensor or thermocouple 28 extends through the shaft 24 and the spider 22 in proximity to the substrate holder 100. Additional peripheral temperature sensors or thermocouples 30 are also shown housed within a slip ring or temperature compensation ring 32, which surrounds the substrate holder 100 and the wafer 16. The thermocouples 28, 30 are connected to a temperature controller (not shown), which controls and sets the power of the various radiant heating elements 14 in response to the readings of the thermocouples 28, 30.

**[0037]** In addition to housing the thermocouples 30, the slip ring 32 also absorbs radiant heat during high temperature processing. As noted in the Background section, the heated slip ring 32 helps to reduce, but not eliminate, heat loss at the wafer edge 17. The slip ring 32 can be suspended by any suitable means. For example, the illustrated slip ring 32 rests upon elbows 34, which depend from the quartz chamber dividers 36.

**[0038]** U.S. Patent Application Serial No. 09/747,173, which is incorporated by reference, discloses a substrate holder designed to minimize problems associated with substrate "slide," "stick," and "curl." Slide occurs when the substrate is dropped onto the substrate holder from above. Slide is normally caused by a cushion of gas above the holder (e.g., in a recess or pocket sized to receive a substrate) that is unable to escape fast enough to allow the substrate to fall immediately onto the holder. The substrate floats momentarily above the holder as the gas slowly escapes, causing the substrate to slide off center. Conversely, stick is the tendency of the substrate holder to cling to the substrate when the substrate is picked up from the substrate holder. Stick occurs because gas is slow to flow into the small space between the substrate and the holder, creating a vacuum effect between

the substrate and the holder. Curl refers to warping of the substrate caused by a combination of both radial and axial temperature gradients therein. Typically, when a substrate is initially inserted into a heated reaction chamber and held above a substrate holder, the center of the substrate is heated disproportionately from below, causing the substrate to curl slightly into a "bowl" or concave-up shape. When the slightly curled substrate is dropped onto a hot wafer holder that does not conform in shape to the substrate (e.g., a flat holder), the curl can be greatly exacerbated. Slide and curl often lead to non-uniformities in processed substrates, and stick can cause particle contamination in the reaction chamber.

**[0039]** The substrate holder disclosed in U.S. Patent Application Serial No. 09/747,173 substantially prevents substrate slide and stick by providing a plurality of intersecting grooves underneath the substrate, which permit the flow of gas to and from the region between the substrate and the holder. The embodiments of the present invention discussed below and shown in Figures 3A-E and 5 represent further modifications of the substrate holder of U.S. Patent Application Serial No. 09/747,173.

**[0040]** Figures 3A-E show a substrate holder 200 according to a preferred embodiment. The holder 200, preferably a susceptor capable of absorbing and re-radiating radiant energy, has features similar to the holder disclosed in U.S. Patent Application Serial No. 09/747,173. The holder 200 is preferably circular and made of graphite coated with silicon carbide, although the skilled artisan will appreciate that other materials are also suitable. The substrate holder 200 has a thickness $t_h$ defined as the distance between upper and lower surfaces.

**[0041]** Figure 3A shows the holder 200 as viewed from the top, that is, looking into a recessed pocket 202. The recessed pocket 202 is a substantially flat surface sized to accommodate a substrate of a particular size (e.g. 200 mm or 300mm wafer). The substrate holder 200 has an annular veined ring 220 on its upper surface configured to support a substrate in a support plane. The veined ring 220 is surrounded by a shallow annular groove 204, as shown in Figures 3A-3C. The shallow annular groove 204 resides radially inward of the annular peripheral side surface 211 of the holder 200. A raised shoulder 206 surrounds the shallow annular groove 204. Figure 3C is an enlarged view of a portion of Figure 3A,

illustrating more clearly the configuration of the annular veined ring 220, shallow annular groove 204, and raised shoulder 206 of the substrate holder 200.

**[0042]** With continued reference to Figures 3A-3C, the shallow annular groove 204 has an annular thickness $t_s$ (along a radial direction for the illustrated round substrate holder). In a preferred embodiment, the thickness $t_s$ is generally uniform. In other embodiments, the thickness $t_s$ varies along its length. The shallow annular groove 204 helps to minimize radiation losses from the substrate to the substrate holder 200. The skilled artisan will understand that as the annular thickness $t_s$ becomes larger, the structural integrity of the holder 200 becomes more compromised, particularly during the silicon carbide coating process during manufacture of the holder, which warps the holder shape. The average annular thickness $t_s$ of the shallow annular groove 204 is preferably less than 1.5 mm. The annular thickness $t_s$ is preferably in the range of 0.5 mm to 2.5 mm, and more preferably 0.7 mm to 1.5 mm.

**[0043]** The shallow annular groove 204 has a vertical depth, defined as the vertical distance between the top surface of the veins 221 and bottom point of the shallow annular groove 204. The vertical depth of the shallow annular groove 204 is preferably at least 15% of the thickness $t_h$ of the substrate holder 200. The vertical depth of the shallow annular groove 204 is in the range of 0.1 mm to 2 mm, and more preferably in the range of 0.4 mm to 0.6 mm. In one embodiment, the vertical depth of the shallow annular groove 204 is preferably at least 0.43 mm.

**[0044]** Figures 3A-3C also show a thermal isolation groove 215 on the substrate holder 200. The thermal isolation groove 215 is an annular groove in the substrate holder 200 positioned radially inward from the annular veined ring 220 and the shallow annular groove 204. The thermal isolation groove 215 is provided to compensate for the heat conduction from the substrate to the substrate holder in the area of the annular veined ring 220, where the substrate is supported by and in thermal contact with the substrate holder. Those of ordinary skill in the art will understand that the groove 215 can have many different, possibly irregular shapes.

**[0045]** The thermal isolation groove 215 has an annular thickness $t_g$ (along a radial direction for the illustrated round substrate holder). In a preferred embodiment, the

thickness $t_g$ is generally uniform. In other embodiments, the thickness $t_g$ varies along its length. Preferably, the annular thickness $t_g$ is large enough to substantially reduce the flow of heat radially outward through the holder 200 and to reduce the gap conductive heat loss by the substrate to the substrate holder 200, and to permit the application of a complete coating of silicon carbide over the entire inner surface of the thermal isolation groove 215. The annular thickness $t_g$ is also preferably small enough to prevent significant flow of gas, and thus convective heat loss, within the thermal isolation groove 215. Also, the skilled artisan will understand that as the annular thickness $t_g$ becomes larger, the structural integrity of the holder 200 becomes more compromised, particularly during the silicon carbide coating process during manufacture of the holder, which warps the holder shape. Such warping introduces concavity to the holder shape, which creates more room to avoid slide and creates less contact between the holder and the substrate in the middle. The average annular thickness $t_g$ of the thermal isolation groove 215 is in the range of 0.3 mm to 5 mm, and more preferably 0.6 mm to 2 mm. In a preferred embodiment, the average annular thickness $t_g$ of the thermal isolation groove 215 is less than 2 mm, more preferably less than 1.5 mm, and more preferably less than 1 mm.

**[0046]** The thermal isolation groove 215 has a vertical depth, defined as the vertical distance between the top surface of the veins 221 and bottom point of the thermal isolation groove 215, that is preferably larger than the vertical depth of the shallow annular groove 204. Preferably, the vertical depth of the thermal isolation groove 215 is large enough to compensate for the conductive heat loss to the substrate from contact with the annular veined ring 220, while also small enough to prevent significant compromise of the structural integrity of the substrate holder 200. The vertical depth of the thermal isolation groove 215 is preferably at least 20% of the thickness $t_h$ of the substrate holder 200. In one embodiment, the vertical depth of the thermal isolation groove 215 is preferably at least 0.5 mm, and no more than 3 mm. More preferably, the vertical depth of the thermal isolation groove 215 is in the range of 0.8 mm to 1.2 mm from the top surface of the veined annular ring 220.

**[0047]** In order to improve thickness uniformity of the substrate and reduce the achievable size of the exclusion zone, it is desirable to further thermally isolate the substrate

16 from the substrate holder 200 to reduce heat loss from the substrate 16 to the substrate holder 200. Figures 3A-3C also show an annular veined ring 220 on the substrate holder 200 in the area between the shallow annular groove 204 and the thermal isolation groove 215.

**[0048]** In this embodiment of the invention, the veined ring 220 has a plurality of veins 221 separated by gaps or channels. The top surfaces of the veins 221 form a substantially flat coplanar (or angled 0 to 10 degrees, and preferably angled 3 degrees) surface configured to support a substrate of a particular size in a support plane defined by the top surfaces of the veins 221. In this embodiment, the annular veined ring 220 supports the substrate 16 only in the area of the "exclusion zone" approximately 1-3 mm radially inward from the edge of the substrate. The annular veined ring 220 is preferably the only point of contact between the substrate 16 and the substrate holder 200 during processing, at least after any curl settles. Aside from this point of contact, there is no other contact between the substrate 16 and the substrate holder 200. As there is little contact between the substrate 16 and the substrate holder 200 in this embodiment, the possibility of damaging the backside of the substrate is reduced. In another embodiment, the top surfaces of the veins collectively form a concave surface that minimizes problems associated with substrate curl. In a preferred embodiment, the veins 221 are oriented at an angle to avoid alignment of the veins 221 with the crystal orientation of the substrate.

**[0049]** Preferably, many veins 221 are provided on the substrate holder 200 to keep the substrate holder 200 cooler because the veins 221 increase heat conduction from the substrate holder 200 to the substrate 16 in the veined region of the substrate holder 200 at the outer edge of the substrate 16. The skilled artisan will appreciate that as the substrate holder 200 is generally at a cooler temperature than the substrate, conduction dominates at the contact points and the channel depths around and in between the veins 221 are selected to compensate for the conductive, convective, and gap conduction interface between the substrate and the substrate holder 200. The veins 221 also provide a gas path for Bernoulli wand pickup as they allow the Bernoulli wand gas to penetrate underneath the substrate. In an embodiment of the invention, there are between 300 and 720 veins 221 in the veined ring 220. Typically, in a preferred embodiment of the invention intended to process a 200 mm wafer, there are more than 300 veins. In an embodiment of the invention intended to process

a 300 mm wafer, there are more than 700 veins. Preferably, for a 300 mm wafer, there are between 250 and 300 veins. The skilled artisan will appreciate that the number of veins is selected to minimize contact damage (e.g., crystalline defects to the substrate).

**[0050]** Figure 3D is an enlarged view of a portion of Figure 3C indicated by arrows 3D-3D. Figure 3E is a cross-sectional view of an of the substrate holder 200 along the line 3E-3E in Figure 3D. As shown in Figures 3D and 3E, the veins 221 are angled, illustrated in a counterclockwise direction at about 45 degrees to the radial direction, and are designed to stop, or promote, gas flow to the backside of the substrate during rotation of the substrate. Alternatively, the veins 221 may be angled in a clockwise direction. Typically, the veins 221 are angled at 30 degrees, more preferably at 45 degrees to the radial direction. Figure 3E shows that the veins 221 are separated from each other by gaps or channels 250.

**[0051]** The thickness $t_v$ of each vein 221 is preferably between 0.2 mm and 2 mm. In a preferred embodiment, the thickness $t_v$ of each vein 221 is 1 mm. Each vein 221 has side walls 244 that slant outward, as shown in Figure 3E. With continued reference to Figure 3E, in a preferred embodiment, the side walls 244 of adjacent veins 221 form a 45-degree angle. There is preferably a flat surface 242 on the bottom of each groove 250 between the veins 221 as shown in Figure 3E. The height of each vein 221, which is defined as the distance between the top surface of a vein 221 and the flat surface 242, is preferably between 0.2 mm and 1 mm. In a preferred embodiment, the height of each vein 221 is 0.4 mm. The distances $d_v$ between the veins 221 is preferably small enough such that there are enough veins 221 provided in the ring 220 to increase heat conduction from the substrate holder 200 to the substrate 16 in the area of the veined ring 220. Preferably, the distance $d_v$ between each vein 221 is between 0.5 mm and 3 mm. In a preferred embodiment, the distance $d_v$ between each vein 221 is about 1.5 mm.

**[0052]** The vertical depth of each channel 250 between veins 221 is equal to the height of each vein 221 in the illustrated embodiment. The vertical depth of each such channel 250 is preferably deep enough to inhibit heat loss at the edge of the substrate by inhibiting the conductive flow of heat radially outward through the substrate holder 200. By doing so, the veins 221 reduce the heat loss from the peripheral side surface 211 of the substrate holder 200. It is believed preferable to have many veins 221 in the veined ring 220

because: (1) the veins 221 reduce most backside deposition, which reduces warping of the wafer during lithographic processes; and (2) they reduce slip and enhance uniformity of the substrate.

**[0053]** The annular veined ring 220 also helps minimize the problems associated with slide, stick, and curl. The veined ring 220 allows gas to penetrate underneath the substrate 16 to minimize "stick" when a substrate 16 is picked up from the substrate holder 200. The veined ring 220, combined with the volume of area underneath the substrate 16, also provides enough area for gas to escape to allow the wafer to drop onto the substrate holder 200 without sliding.

**[0054]** Figure 3B is a cross-sectional view of an area near the periphery of the substrate holder 200 along the line 3B-3B in Figure 3A. The shallow annular groove 204, the raised shoulder 206, the thermal isolation groove 215, and the annular veined ring 220 are shown in Figure 3B. Preferably, the top surfaces of the veins 221 are substantially parallel to the top surface of the raised shoulder 206. In an alternative embodiment, the top surfaces of the veins 221 are angled to the top surface of the raised shoulder 206.

**[0055]** On a bottom surface 210, the substrate holder 200 has a bottom groove 208 centered about a central vertical axis of the substrate holder 200. The bottom groove 208 is configured to receive upper ends of the substrate holder supporters or arms 25 of the spider 22 (Figure 2). Figure 4, which shows a bottom plan view of the holder 200, illustrates a preferred configuration of the bottom groove 208. The illustrated bottom groove 208 comprises a single groove and does not form a complete circle but is interrupted by a section 114, shown on the right side of Figure 4. The interrupting section 114 ensures that the spider 22 cannot rotate independently of the substrate holder 200 once it has locked in position against section 114. A more detailed description of a bottom groove such as bottom groove 208 is provided in U.S. Patent Application Serial No. 09/747,173. In an alternative embodiment, the substrate holder does not have a bottom groove. Instead, the holder has a plurality of recesses, each configured to closely receive one of the upper ends of the substrate holder supporters 25 of the spider 22. The skilled artisan will appreciate that there are alternative methods of centering the substrate holder to the holder support.

**[0056]** In a preferred embodiment of the invention, the substrate holder 200 includes a raised feature 230 approximately near the edge of the substrate (assuming the substrate is centered on the substrate holder, where the substrate and the substrate holder have the same center), as shown in Figures 5A and 5B. Figure 5A is a top plan view of the substrate holder 200 according to this embodiment, and Figure 5B is a cross-sectional view, taken along line 6B-6B in Figure 5A. The view in Figure 5B extends from a vertical center axis 240 of the substrate holder to the raised shoulder 206. Only a portion of the raised shoulder 206 is shown in Figure 5B.

**[0057]** The region of the substrate holder 200 in which the raised feature 230 s preferably located is approximately near the edge of the substrate. For example, on a 300 mm substrate, the raised feature is preferably in an area that is approximately 100mm to 140 mm from the vertical center axis 240 and radially inward from a radially inward edge of the shallow annular groove 204. The raised feature 230 is a raised annular ring that, when a substrate 16 is supported on the substrate holder 200, is very close to, but not touching, the substrate 16, as shown in Figure 5B. Due to the configuration of the radiant heat lamps 14 in the apparatus described in connection with this embodiment, the substrate 16 is generally at a higher temperature than the substrate holder 200 in the region of the raised feature 230. As the raised feature 230 is so close to the substrate 16, the raised feature 230 also increases heat loss from the substrate 16 to the substrate holder 200 in this region of the substrate holder 200 to compensate for the higher temperature of the substrate 16 in this region caused by the configuration of the radiant heat lamps 14 in this embodiment, which is also described in U.S. Patent No. 6,121,061. The raised feature 230 pulls out additional heat energy from the substrate 16 to the substrate holder 200 as there is more heat flow in the substrate 16 in the raised feature 230 region. The raised feature 230 also reduces the effects of the overlapping radiation view angle from the front, side, and rear radiant heat lamps 14 with the center radiant heat lamps 14 of the apparatus during steady state CVD deposition (generally at temperatures under 950°C.

**[0058]** Although this invention has been disclosed in the context of certain preferred embodiments and examples, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiments to other alternative

embodiments and/or uses of the invention and obvious modifications and equivalents thereof. Further, the various features of this invention can be used alone, or in combination with other features of this invention other than as expressly described above. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiments described above, but should be determined only by a fair reading of the claims that follow.